PB-245 125

PROCESS ALTERNATIVES FOR REMOVAL OF CARBONACEOUS, NITROGENOUS, AND PHOSPHORUS MATERIALS FROM CONCENTRATED WASTE STREAMS

Engineering Science, Incorporated

Prepared for:

Federal Water Quality Administration

November 1970

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1 Accession Number	2 Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM
W	05D	

5 Organization: Engineering-Science, Inc.
Research & Development Laboratory
Oakland, CA 94609

6 Title: PROCESS ALTERNATIVES FOR REMOVAL OF CARBONACEOUS, NITROGENOUS, AND PHOSPHORUS MATERIALS FROM CONCENTRATED WASTE STREAMS

10 Author(s): Contract Report

16 Project Designation: Contract #14-12-431, Program Number 17010 EVB, November 1970, 15p.

21 Note:

22 Citation:

23 Descriptors (Starred First): *Nutrients, *Process Selection, Chemical Treatment, Physical Processes, Evaluation, Quality Objectives

25 Identifiers (Starred First): *Precipitation, Lime, Alum, Iron, Nitrogen Removal, Solids Effect, Cost

27 Abstract:

Laboratory and bench scale studies were used to guide process selection for treating digester supernatant before recycle to the main wastewater flow. Various chemical precipitants and physical processes were employed. Various levels of effluent quality were determined and a computer program was developed to identify levels of cost associated with each process.

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WR:102 (REV. JULY 1969)
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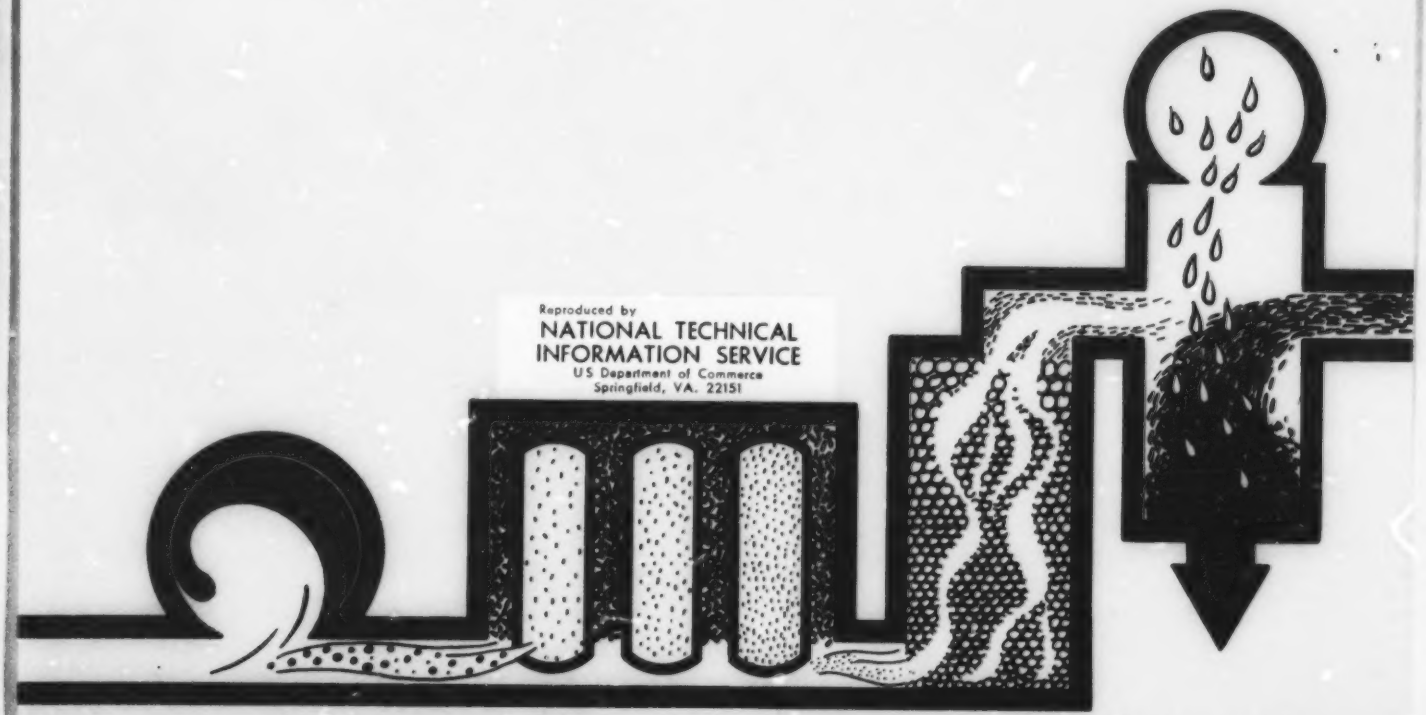

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by

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for the

WATER QUALITY OFFICE
ENVIRONMENTAL PROTECTION AGENCY

Program #17010 EVB
Contract #14-12-431
EPA Project Officer, E. F. Barth
Advanced Waste Treatment Research Laboratory
Cincinnati, Ohio
November, 1970

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 35 cents

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ABSTRACT

An approach is described for assessing the economic feasibility of treating concentrated waste streams for the removal of carbon, nitrogen, and phosphorus (CNP) constituents. Candidate process train alternatives (using conventional wastewater treatment processes) were formulated on the basis of laboratory evaluations to assess the feasibility of these processes for separation and/or conversion of CNP constituents from concentrated waste streams. A treatment system simulation model is described which is capable of tracking material (CNP) flows through the candidate process trains, predicting the removal of CNP materials in each process on the basis of relationships formulated from the laboratory studies, computing costs for each feasible process train in the candidate trains for the specific input concentrated waste stream flow rate and quality, and selecting the least cost alternative for treatment of the stream to specified quality levels. The simulation model is used to evaluate the least costs for treatment of 10 specific concentrated waste streams at three flow rates and for two specific effluent quality levels.

This report was submitted in fulfillment of Contract No. 14-12-431, Program No. 17010 EVB, between the Federal Water Quality Administration and Engineering-Science, Inc.

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INTRODUCTION

The growing national concern for water quality has cast new attention on the control of traditionally difficult-to-manage wastewaters such as concentrated waste streams from municipal and industrial sources. From a treatment viewpoint, concentrated waste streams are defined as raw wastewaters or treatment system byproducts which are not amenable directly to treatment by the conversion and separation processes used in conventional municipal water pollution control facilities. Digester supernatants, vacuum filter filtrates, centrates, and industrial waste liquors are typical concentrated waste streams.

The aerobic and anaerobic biological treatment processes commonly found in municipal pollution control facilities have not afforded a general solution for the treatment of concentrated waste streams. Inevitably, the organic strength of a concentrated waste stream will exceed the maximum level ($\sim$ 800 mg/ℓ as COD) acceptable for treatment ($\sim$ 10,000 mg/ℓ as COD) required for treatment by anaerobic digestion. In the latter case dilution of the concentrated waste stream is usually necessary before biological treatment can be accomplished. Many of the biological and other treatment processes used in municipal facilities have a limited capacity for nitrogen and phosphorus removal; some biological processes, such as anaerobic digestion, actually cause the conversion of organic nitrogen and phosphorus to soluble forms. For the lack of treatment alternatives, it is frequently necessary to dilute concentrated waste streams, or treatment system byproducts, with municipal plant influents or effluents. This practice ultimately results in an essentially uncontrolled discharge of the constituents in these waters.

The current trend in water quality criteria is to place increasingly severe limitations on the acceptability of treated effluents for discharge to receiving waters, particularly with respect to carbon, nitrogen, and phosphorus constituents. The treatment of concentrated waste streams and treatment system byproducts offers a potentially attractive alternative for meeting new criteria, particularly because of the opportunity to use, advantageously, the high constituent concentrations of these streams in treatment approaches. The initial activity in assessing the economic feasibility of treating concentrated wastes requires the selection of unit process and treatment system alternatives; the major steps in the activity are the identification of candidate unit processes and treatment systems, laboratory evaluation of the selected processes and systems, and preliminary assessment of cost and performance feasibility of the process followed as appropriate by pilot-scale studies to complete development of design criteria and a costing basis. The initial identification of candidate processes and systems can be a formidable task, particularly when it is desired to base the initial identification process on a comparative cost basis.

The present paper summarizes an approach to facilitating the economic and performance tradeoffs between candidate process alternatives for treatment of concentrated waste streams. The approach is based on the findings of a recent study which:

(1) The capability of conventional wastewater treatment processes for modifying concentrated waste streams were evaluated.

(2) Alternative treatment systems were formulated from the unit processes.

(3) The technical and economic feasibility of the alternatives were evaluated by a treatment system simulation model to permit selection of the least cost alternative(s) for treatment of concentrated waste streams to a specific quality level.

APPROACH

The basic performance objective selected for treatment of concentrated waste streams was that the quality of the treatment system effluent should be equivalent to typical quality levels of either raw domestic sewage or secondary effluents from municipal wastewater treatment facilities. The premises used in formulating the treatment systems were that the removal of carbon, nitrogen, and phosphorus should be considered alternatively or in combination in the systems and that the treatment systems could be formulated by linking of separation and conversion processes. Laboratory treatability studies were conducted to document the performance of the following processes:

- Separation Processes: gravity sedimentation; vacuum filtration; centrifugation; dissolved air flotation; sand filtration; microscreening; and ammonia stripping.

- Conversion Processes: coagulation (chemical solids conditioning); precipitation (phosphorus conversion); ammonium ion exchange; and activated carbon treatment.

Digester liquor was selected as a representative type of concentrated waste stream for laboratory testing with the above processes. Digester liquor typically has the following characteristics: suspended solids, 20,000 mg/ℓ; volatile fraction, 30 percent; nonsettleable phosphorus, 200 mg/ℓ; and ammonia nitrogen, 700 mg/ℓ. The major effort of the laboratory inquiry was directed to the study of the conversion of nonseparable solids produced by the conversion processes and the removal of ammonia nitrogen from the concentrated waste. Lime, alum, ferric chloride, and polymer Magnifloc 521-C were evaluated for efficiency of solids conversion by coagulation; and, lime, alum, and ferric chloride were evaluated for efficiency of conversion of soluble

phosphorus to a settleable form.

DOCUMENTATION OF UNIT PROCESS PERFORMANCE

Based on the laboratory studies, all of the above unit processes except microscreening, sand filtration, activated carbon treatment; dissolved air flotation, and ammonium ion exchange were found satisfactory for inclusion as process alternatives in treatment of concentrated waste streams. Additionally, anaerobic digestion, wet air oxidation, and incineration were included as candidate treatment processes for alternative treatment systems. The performance of all the processes was documented by the formulation of material, liquid, and heat balances where appropriate, and by development of specific relationships between extensive parameters (such as chemical dosage per unit of solids or phosphorus present) and rate parameters (such as surface loading rates, gal/day/sq ft, or mass loading rates, lb/day/sq ft). The documentation expression provided a basis for routing of all important characteristics into the process, their conversion or separation within, and outflow from each unit process. The characteristics selected for tracking in all processes were: suspended solids (in lieu of COD), ammonia nitrogen, nonsettleable phosphorus, volatile solids fraction, and wastewater temperature and heat content.

The purpose of the chemical solids conditioning process was to convert nonseparable solids to separable solids. The phosphorus conversion process served the function of converting nonseparable phosphorus to a separable form; the process may be used in conjunction with chemical solids conversion or as a separate process. Two types of separation were encountered in conjunction with the above: gravity settling of the effluent of the chemical solids conditioning process exhibited zone settling; whereas, the settling of effluents from the phosphorus conversion process exhibited Class II (flocculant) clarification.

The basic parameter selected for the gravity thickening process was the surface area required per day per lb of applied solids. Expressions were developed from the laboratory data relating required surface area with initial and desired underflow concentration for chemical solids conditioning with alum, lime, polymer, ferric chloride, as well as with no chemical treatment.

Vacuum filtration was considered technically feasible as a process at solids levels greater than 30,000 mg/ℓ provided the solids were found in the laboratory program to be amenable to filtration. The relative filterability of sludges was influenced significantly by the type and quantity of chemical used; process behavior with alum,

lime, ferric chloride, and polymer were documented. Equations were developed on the assumption that a 70 percent moisture content would be achieved in the cake.

Material balance expressions were developed for the centrifugation process on the assumption that a 96 percent solids recovery could be achieved and that the moisture content of the recovered solids would be 60 percent for the lime-treated solids and 85 percent for alum, ferric chloride, and polymer-treated solids. Two first-order expressions were developed to describe the ammonia stripping process: an expression relating input and output solute ammonia concentrations, and an expression relating the mass transfer coefficient in the above expression to temperature.

The anaerobic digestion and wet air oxidation processes were documented in terms of solids input-output and conversion of insoluble nitrogen and phosphorus to soluble output phosphorus. The incineration process was documented in terms of specific heat balances based on mass loading rate of input dry solids, inert solids, volatile solids, and the water and heat content of volatile solids.

SELECTION OF ALTERNATIVE TREATMENT SYSTEMS

The selection of alternative treatment systems required a dual-level selection inquiry. The first level related to the components of the concentrated waste stream, the treatment objective and the probable treatment techniques, and resulted in the selection of a particular treatment system or group of treatment systems. The primary selection procedure was accomplished by inquiry regarding the constituents present in the wastewater and the form of treatment applicable. The inquiries, initial processes, and treatment systems applicable are shown in Figure 1, and the detailed treatment systems are shown in Figures 2 to 7.

Treatment System (TS) 1 (shown in Figure 2) was used for treatment of biodegradable solids or combustible solids, and contains six ***system trains*** (or process sequences) variously applicable as a function of how the solids are handled. The six system trains, all initiated by chemical solids conditioning and terminated by phosphorus removal, incineration and land disposal, are: (1) zone clarification (ZC), gravity thickening (GT), and vacuum filtration (VF); (2) XC, GT, centrifugation (CENT); (3) FT, VF; (4) GT, CENT; (5) VF alone; (6) CENT alone. Sludges from phsophorus removal can be treated either by vacuum filtration or centrifugation directly or else preceded by gravity thickening, depending on the system train considered. Inasmuch as any of four chemicals (alum, lime, ferric chloride, or polymer) can be selected

for solids conditioning, and any of three chemicals (alum, lime, or ferric chloride) can be considered for phosphorus removal, there exist 12 ***subalternatives*** in each system train, or a total of 72 subalternatives in TS I.

TS II (Figure 3) was also used for treatment of biodegradable or combustible solids. The output solids from the wet air oxidation process were assumed to be filterable without chemical conditioning. There exists one system train and three subalternatives (phosphorus removal) in TS II. TS III (Figure 4) was used only for treatment of biodegradable solids. TS III is similar to TS I, but incorporates anaerobic digestion in lieu of incineration. Six system trains (as identified for TS I), each with 12 subalternatives, exist in TS III.

TS IV (Figure 5) was designed for treatment of streams containing vacuum-filterable solids at concentrations less than 30,000 mg/ℓ (i.e., less than assumed desirable for vacuum filtration). One system train and three subalternatives (for phosphorus removal) exist in TS IV. TS V was used in conjunction with streams containing vacuum-filterable solids at concentrations greater than 30,000 mg/ℓ and, with exception of gravity thickening, is identical to TS IV. TS VI (Figure 6) was used for streams containing solids requiring chemical conditioning prior to vacuum filtration. There are six system trains in TS VI, as discussed previously for TS I. Twelve subalternatives occur for each system train (four for chemical solids conditioning and three for phosphorus removal). TS VII and VIII (Figure 7) were applied for the treatment of streams essentially free of suspended solids. TS VII was used for phosphorus removal and TS VIII for ammonia-nitrogen stripping. One subalternative exists in each of these treatment systems. A total of 23 system trains and 229 subalternatives were considered for all eight treatment systems.

The secondary selection process (after selection of the initial process and the applicable treatment system(s)) required the selection of the system train and subalternative in each treatment system to provide treatment of the waste stream. Treatment objectives were selected with reference to municipal waste treatment facilities, where the need for management of concentrated waste streams is most critical. Two sets of objectives were considered for treatment of concentrated waste streams: (1) treatment to influent (raw domestic sewage) quality (suspended solids $\leq$ 300 mg/ℓ, ammonia-nitrogen $\leq$ 30 mg/ℓ, and total phosphorus $\leq$ 10 mg/ℓ as P); and (2) treatment to effluent quality (suspended solids $\leq$ 25 mg/ℓ, ammonia-nitrogen $\leq$ 5 mg/ℓ, and total phosphorus $\leq$ 1 mg/ℓ).

ECONOMIC EVALUATION OF ALTERNATIVES

Unit Process Costs

Functional relationships for capital and operating costs of all unit processes were obtained from Smith *et al* (Reference 1); all cost relationships were adjusted to reflect estimated 1970 costs according to the *"Engineering News Record"* Cost of Contruction Index. Unit process costs considered in the economic evaluation included chemicals, electrical power, maintenance of mechanical equipment, auxillary heat energy, and water. Chemical costs per ton for operation were taken as: lime, $25; alum, $60; ferric chloride, $240; and polymer, $400. Because of geographical specificity, costs for land and labor for operation and routine maintenance associated are not generally quantifiable and were not included. To establish a common basis for presenting costs, all unit cost functions were structured to compute components costs in units of dollars per day. The capital construction costs of all unit processes were obtained for reference information and converted to annual cost of amortization over a 20-year period at five percent interest. Daily cost of capital construction was taken at 1/365th of the annual cost. The cost estimates do not include costs for unit process linkage (pumps, pipes, etc.) or for removal of solids to landfill sites.

Economic Evaluation

The economic evaluation required the selection of input concentrated waste streams to be evaluated with respect to the process alternative, and the definition of a protocol for conducting the evaluation. Four input streams were selected for the evaluation: digester liquor, digester supernatant liquor, a composite of 50 percent primary sludge-50 percent activated sludge, and a sludge thickener overflow.

The basic premise in the determination of the least costly ***system train*** was that the overall cost for any ***system train*** is the sum of the least cost subalternative for each unit process in the system train. Thus, the least cost estimate of treatment was defined as the sum of costs for discrete unit process behavior rather than as a continuous function of the performance of all the unit processes. The Engineering-Science Treatment System Selector (ESTSS) Program was used to facilitate the computation process. The ESTSS Program, given the appropriate input data, forced the selection of these treatment systems which can provide treatment of the wastewater to meet the pre-set objectives described previously. The subalternatives for each system train of each valid treatment system were determined by the number of independent chemical additions needed for chemical solids conditioning and/or phosphorus removal and the number of different chemicals

considered. The computation procedure automatically cycled through all treatment systems capable of treating the waste stream and through each of the system trains therein. The least cost alternative and the chemical(s) used therein, as well as the unit process characteristics, were presented as program output. Each waste stream type was considered at three concentrated waste stream flow rates: 30,000 gpd; 300,000 gpd; and 3,000,000 gpd.

The input characteristics for each of the above four concentrated waste streams are shown in Table I in a framework of 10 Test Runs. The specific input characteristics are suspended solids, nonsetteable phosphorus, ammonia-nitrogen, information on the primary selection inquiries relating to digestability, combustibility, and vacuum filterability, and the treatment objectives. Test Runs 1 to 4 were conducted with a digester liquor which was to be treated to meet the two levels of objectives, and within each treatment objective, to be evaluated as containing either combustible or noncombustible solids. Test Runs 5 and 6 were conducted with a digester supernatant liquor which was to be treated to meet the two levels of objectives. Test Runs 7 and 8 were conducted with a mixture of 50 percent primary sludge-50 percent waste activated sludge. Both the thickener overflow and the sludge mixture were to be treated to meet the two levels of objectives.

Results

The results of the least cost treatment system analysis using the ESTSS Program are presented in Table 2, and include the least cost alternative, (i.e., treatment system and system train), the daily treatment cost (capital plus operation costs), and the chemicals selected for solids conditioning and phosphorus removal for the least cost alternative at each flow rate. The treatment of combustible anaerobic digester liquor to municipal treatment plant influent and effluent quality levels by either Treatment System I or II was considered in Tests 1 and 3. TS II (System Train II-1, using alum for phosphorus removal) provided the least cost treatment for both treatment objective levels and for all three flow rates.

Evaluated in Tests 2 and 4 was the treatment of a digester liquor which was assumed to be neither combustible nor readily filterable (i.e., only system trains in TS VI could be used). System Train VI-4 incorporating gravity thickening and centrifugation for solids handling was found to be most economical for treatment to influent quality at all flow rates. Two different system trains were required for least cost treatment of digester liquor to effluent objectives; at 30,000 gpd, System Train VI-3 (utilizing lime for chemical solids conditioning and phosphorus removal and incorporating vacuum filtration following gravity thickening for solids separation); and at 300,000 and 3,000,000 gpd, System Train VI-4 (using polymer for solids conditioning, alum for phosphorus removal, and centrifugation for solids separation).

The least cost for treatment of digester supernatant liquor was determined in Tests 5 and 6. System Train VI-4 (gravity thickening and centrifugation) was selected when influent objectives were considered, and System Train VI-3 (gravity thickening and vacuum filtration) was selected for the more stringent effluent quality requirements. Thickener overflow treatment was evaluated in Tests 7 and 8. The least cost treatment for thickener overflows was found to be attained with System Train VI-3 at lower flow rates and System Train VI-4 at higher flow rates.

The least cost treatment for the primary and activated sludge mixture at all three flow rates (Tests 9 and 10) was found to be anaerobic digestion followed by gravity thickening. System Train III-4 (using gravity thickening) and III-3 (gravity thickening and vacuum filtration) was selected for treatment to effluent quality.

DISCUSSION

The daily treatment cost for each of the four concentrated waste streams analyzed was found to increase as the flow increased, but not at the same rate. Each ten-fold increase in flow rate was accompanied by a daily treatment cost increase of seven to nine-fold, indicating that a significant economy of scale is associated with each of the treatment systems defined as a result of the least cost selection procedures.

According to the data of Tests 1 through 8 in Table 2, a significant decrease in daily treatment cost was observed as the magnitude of constituent concentrations decreased from those in digester liquor to those of thickener overflow. However, the decreases in cost were not commensurate with the corresponding decreases in constituent concentration. The average decrease in daily treatment cost between digester liquor and digester supernatant liquor for all three flows was approximately 50 percent; the corresponding decrease in concentrations of suspended solids, phosphorus, and ammonia were 72 percent, 50 percent, and zero respectively. The average decrease in daily treatment cost between digester liquor and thickener overflow was approximately 80 percent; the corresponding decrease in concentrations of suspended solids, phosphorus, and ammonia were 98 percent, 99 percent, and 89 percent respectively. Consequently, lower unit costs should result from the treatment of highly concentrated waste streams than from the treatment of diluted waste streams. The preceding relationships reflect the saturation functions between performance and chemical dosages observed in the laboratory studies.

The difference in daily treatment costs between Tests 1 and 3 and Tests 2 and 4 was in the use of wet air oxidation in the former tests. Although wet air oxidation (Figure 3) further reduced the solids content in digester liquors and precluded chemical solids conditioning prior to vacuum filtration, it was found to increase the daily treatment cost three to four times over the cost of treatment using Treatment System VI (Figure 6).

The preceding discussion has considered only those system trains associated with the least cost on a cost per day basis. However, it is evident from the data of Table 2 that in many instances the differences between the daily costs generated from the modeling-simulation process is not of sufficient magnitude to justify selection of one system train over the other. This situation reflects the characteristics of the experimental data and certain assumptions which were required to accomodate the inclusion of incineration, wet air oxidation, and anaerobic digestion in the treatment systems. Thus, the selection between system trains of nearly equal cost should be done on a basis other than cost or after the development of a more refined cost analysis.

Finally, any consideration of the cost data must be done in appreciation of the fact that data is developed from laboratory information through the application of mathematical modeling. While such an approach can describe trends and relative cost situations it must not be confused with prototype data with regard to either accuracy or significance. The most important parameter with respect to the preceding is the scale-up factor of the laboratory data used to characterize the unit processes. This latter situation can only be resolved by increasing the data reservoir for laboratory, pilot plant, and full-scale prototype systems providing treatment of concentrated waste streams.

CONCLUSIONS

The basic conclusions of the study were:

- The basic technology available for evaluating unit process performance is generally applicable for evaluating the treatability of concentrated waste streams.

- The laboratory results and associated cost analysis indicate that certain treatment systems can be used, at the present stage of development of technology, to successfully treat concentrated waste streams. Specific unit processes which can be applied are chemical solids and phosphorus conversion,

gravity thickening, vacuum filtration and centrifugation, and ammonia air stripping.

A computer program such as ESTSS should be used to define alternative treatment systems to be considered in more detail for any particular waste stream; and to define the areas in which additional investigative efforts are most likely to have the greatest return in terms of improved treatment capabilities.

TABLE 1

CHARACTERISTICS OF CONCENTRATED WASTE STREAMS

FOR LEAST COST EVALUATION

Test Run	Input Characteristics						Treatment Objectives			Primary Selection Inquiries		
	Suspended Solids (X_i^S, mg/l)	Non-settleable Phosphorus (X_i^P, mg/l)	Ammonia Nitrogen ($X_i^{NH_3}$, mg/l)	Volatile Fraction	Heat Content (btu/lb)	Temperature (°C)	Suspended Solids (X_o^S, mg/l)	Non-settleable Phosphorus (X_o^P, mg/l)	Ammonia Nitrogen ($X_o^{NH_3}$, mg/l)	Digestability	Combustability	Filterability
1	20,000	200	700	0.30	4,000	23	300	10	30	No	Yes	No
2	20,000	200	700	0.30	4,000	23	300	10	30	No	No	No
3	20,000	200	700	0.30	4,000	23	25	1	5	No	Yes	No
4	20,000	200	700	0.30	4,000	23	25	1	5	No	No	No
5	5,600	100	700	0.70	5,000	20	300	10	30	No	No	No
6	5,600	100	700	0.70	5,000	20	25	1	5	No	No	No
7	800	2	75	0.70	5,000	18	300	2	30	No	No	No
8	800	2	75	0.70	5,000	18	25	1	5	No	No	No
9	19,200	50	55	0.70	10.000	14	300	10	30	Yes	Yes	No
10	19,200	50	55	0.70	10,000	14	25	1	5	Yes	Yes	No

NOTES: Test Runs 1, 2, 3, and 4 represent digester liquor.
Test Runs 5 and 6 represent digester supernatant liquor.
Test Runs 7 and 8 represent thickener overflow.
Test Runs 9 and 10 represent 50 percent primary sludge and 50 percent waste activated sludge.

TABLE 2

SUMMARY OF LEAST COST TREATMENT SYSTEMS FOR CONCENTRATED WASTE STREAMS
FLOW RATE = 30,000 gpd

Test Run*	Waste Stream	Treatment Objective	Least Cost Treatment System			
			System Train	Total Cost, $/day	Chemical Used For	
					Chemical Solids Conditioning	Phosphorus Removal
1	Digester Liquor	Influent Quality	II-1	227	-	Alum
2	Digester Liquor	Influent Quality	VI-4	62	Alum	Lime
3	Digester Liquor	Effuent Quality	II-1	254	-	Alum
4	Digester Liquor	Effluent Quality	VI-6	122	Lime	Lime
5	Digester Supernatant Liquor	Influent Quality	VI-4	38	Alum	Lime
6	Digester Supernatant Liquor	Effluent Quality	VI-3	53	Lime	Lime
7	Thickener Overflow	Influent Quality	VI-3	16	Lime	Lime
8	Thickener Overflow	Effluent Quality	VI-3	23	Lime	Lime
9	50 percent Primary sludge and 50 percent Waste Activated Sludge	Influent Quality	III-4	84	Alum	Lime
10	50 percent Primary sludge and 50 percent Waste Activated Sludge	Effluent Quality	III-3	132	Lime	Lime

NOTE: * See Table 1 for description of test conditions.

TABLE 2 (Cont'd)

SUMMARY OF LEAST COST TREATMENT SYSTEM FOR CONCENTRATION WASTE STREAMS
FLOW RATE = 300,000 gpd

Test Run*	Waste Stream	Treatment Objective	Least Cost Treatment System			
			System Train	Total Cost, $/day	Chemical Used For	
					Chemical Solids Conditioning	Phosphorus Removal
1	Digester Liquor	Influent Quality	II-1	1,509	-	Alum
2	Digester Liquor	Influent Quality	VI-4	422	Alum	Lime
3	Digester Liquor	Effluent Quality	II-1	1,732	-	Alum
4	Digester Liquor	Effluent Quality	VI-6	979	Polymer	Alum
5	Digester Supernatant Liquor	Influent Quality	VI-4	194	Alum	Lime
6	Digester Supernatant Liquor	Effluent Quality	VI-3	340	Lime	Lime
7	Thickener Overflow	Influent Quality	VI-4	58	Alum	Lime
8	Thickener Overflow	Effluent Quality	VI-3	78	Lime	Lime
9	50 Percent Primary sludge and 50 percent Waste Activated Sludge	Influent Quality	III-4	576	Alum	Lime
10	50 percent Primary sludge and 50 percent Waste Activated Sludge	Effluent Quality	III-3	1,030	Alum	Lime

NOTE: * See Table 1 for description of test conditions.

TABLE 2 (Cont'd)

SUMMARY OF LEAST COST TREATMENT SYSTEMS FOR CONCENTRATED WASTE STREAMS
FLOW RATE = 3,000,000

Test Run*	Waste Stream	Treatment Objective	Least Cost Treatment System			
			System Train	Total Cost, $/day	Chemical Used For	
					Chemical Solids Conditioning	Phosphorus Removal
1	Digester Liquor	Influent Quality	II-1	13,389	-	Alum
2	Digester Liquor	Influent Quality	VI-4	3,832	Alum	Lime
3	Digester Liquor	Effluent Quality	II-1	15,509	-	Alum
4	Digester Liquor	Effluent Quality	VI-6	9,526	Polymer	Alum
5	Digester Super-natant Liquor	Influent Quality	VI-4	1,613	Alum	Lime
6	Digester Super-natant Liquor	Effluent Quality	VI-3	3,021	Alum	Lime
7	Thickener Overflow	Influent Quality	VI-4	343	Alum	Lime
8	Thickener Overflow	Effluent Quality	VI-4	468	Polymer	Lime
9	50 percent Primary sludge and 50 percent Waste Activated Sludge	Influent Quality	III-4	5,250	Alum	Lime
10	50 percen Primary sludge and 50 percent Waste Activated Sludge	Effluent Quality	III-3	9,710	Alum	Lime

NOTE: * See Table 1 for description of test conditions.

LIST OF REFERENCES

1. Smith, Robert, *"A Compilation of Cost Information for Conventional and Advanced Wastewater Treatment Plants and Processes"*, FWPCA, US Department of Interior, (December 1967).

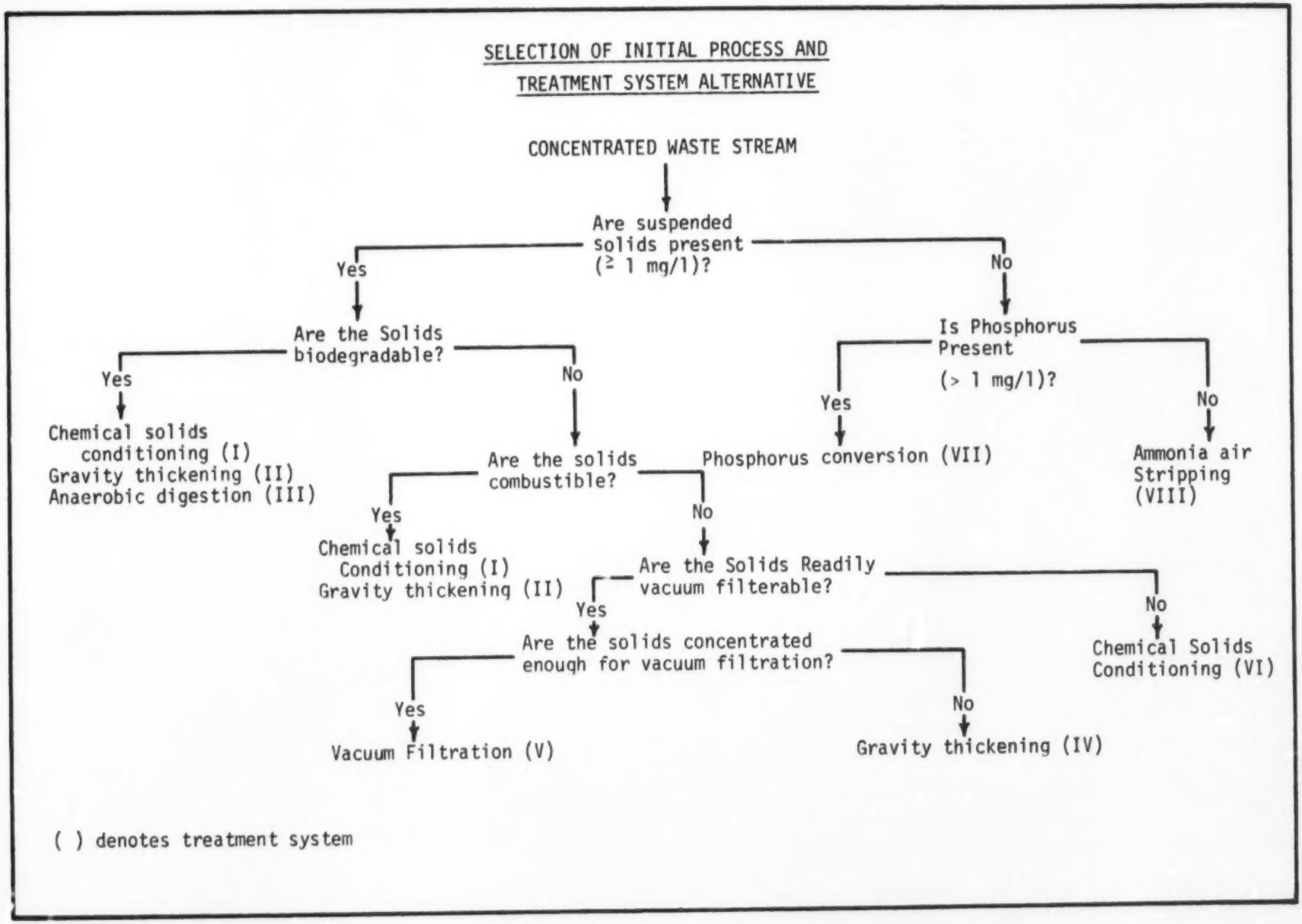

SELECTION OF INITIAL PROCESS AND TREATMENT SYSTEM ALTERNATIVE
CONCENTRATED WASTE STREAM
Are suspended solids present (≥ 1 mg/l)?
Yes
No
Are the Solids biodegradable?
Yes
No
Chemical solids conditioning (I)
Gravity thickening (II)
Anaerobic digestion (III)
Are the solids combustible?
Yes
No
Chemical solids Conditioning (I)
Gravity thickening (II)
Are the Solids Readily vacuum filterable?
Yes
No
Are the solids concentrated enough for vacuum filtration?
Yes
No
Vacuum Filtration (V)
Gravity thickening (IV)
Chemical Solids Conditioning (VI)
Is Phosphorus Present (> 1 mg/l)?
Yes
No
Phosphorus conversion (VII)
Ammonia air Stripping (VIII)
( ) denotes treatment system

FIGURE 1

TREATMENT SYSTEM I

PROCESS SEQUENCE AND FLOW DIAGRAM

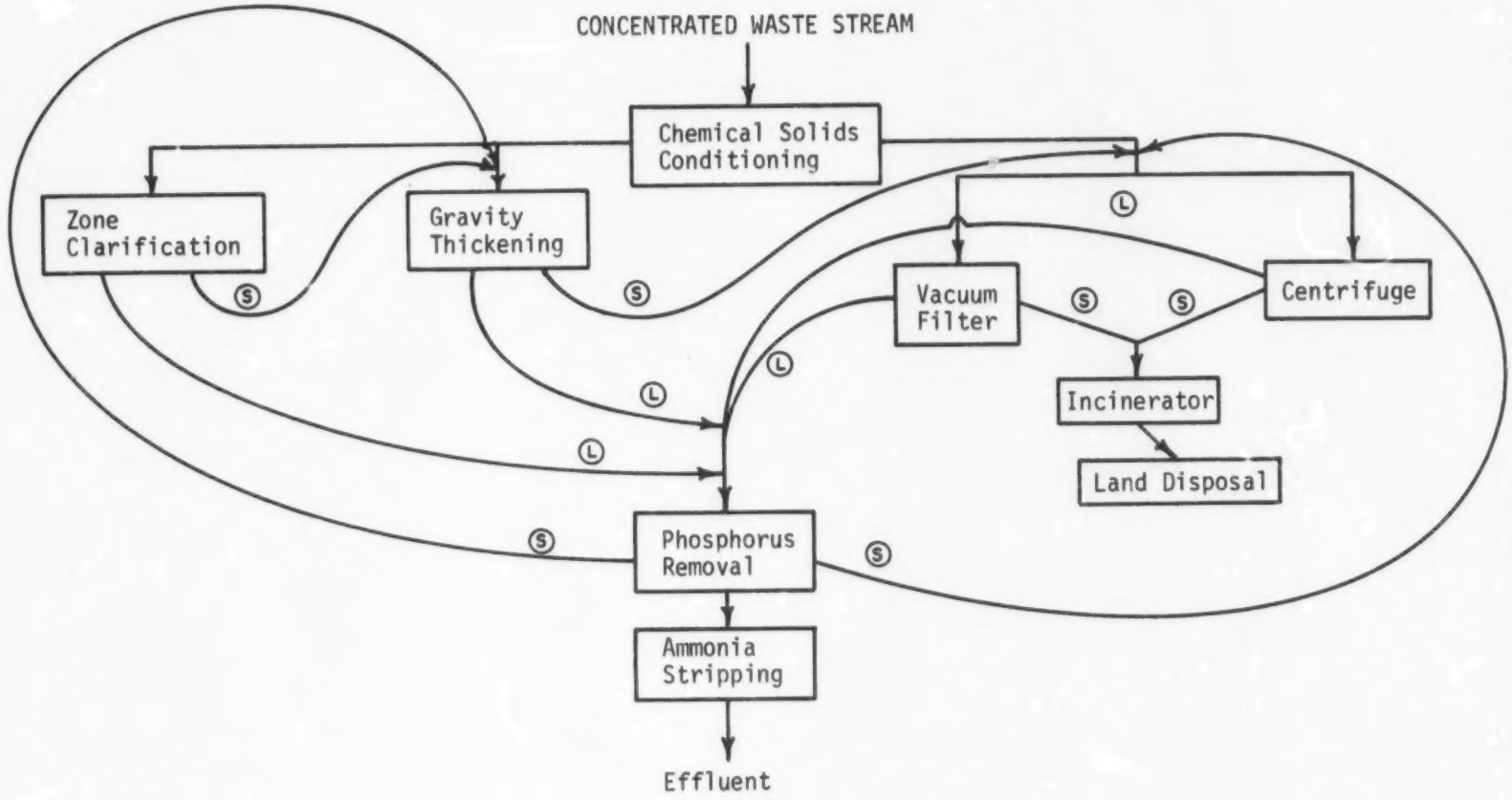


FIGURE 2

TREATMENT SYSTEM II

PROCESS SEQUENCE AND FLOW DIAGRAM

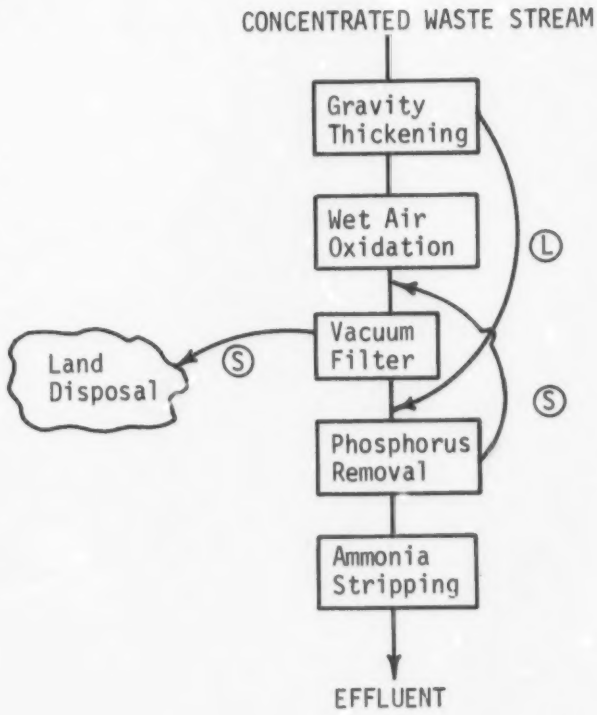


FIGURE 3

TREATMENT SYSTEM III

PROCESS SEQUENCE AND FLOW DIAGRAM

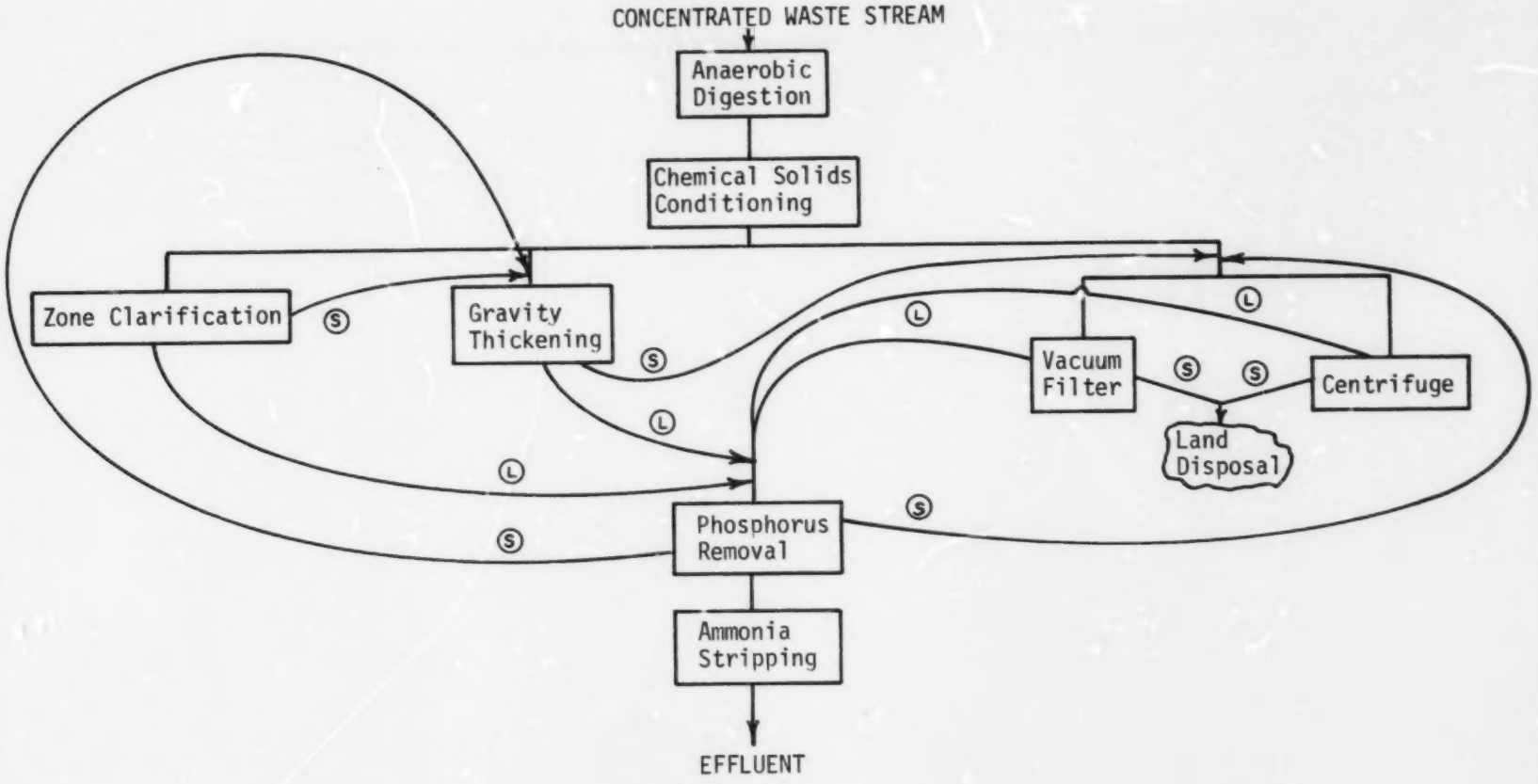
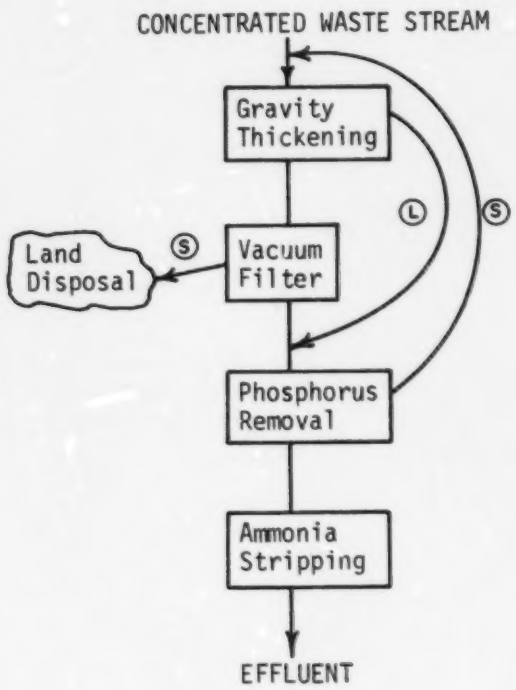
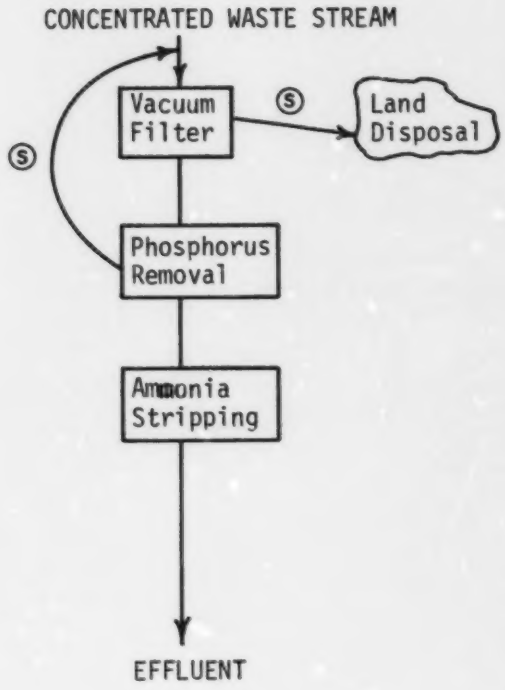


FIGURE 4

TREATMENT SYSTEMS IV AND V
PROCESS SEQUENCE AND FLOW DIAGRAM



TREATMENT SYSTEM IV



TREATMENT SYSTEM V

FIGURE 5

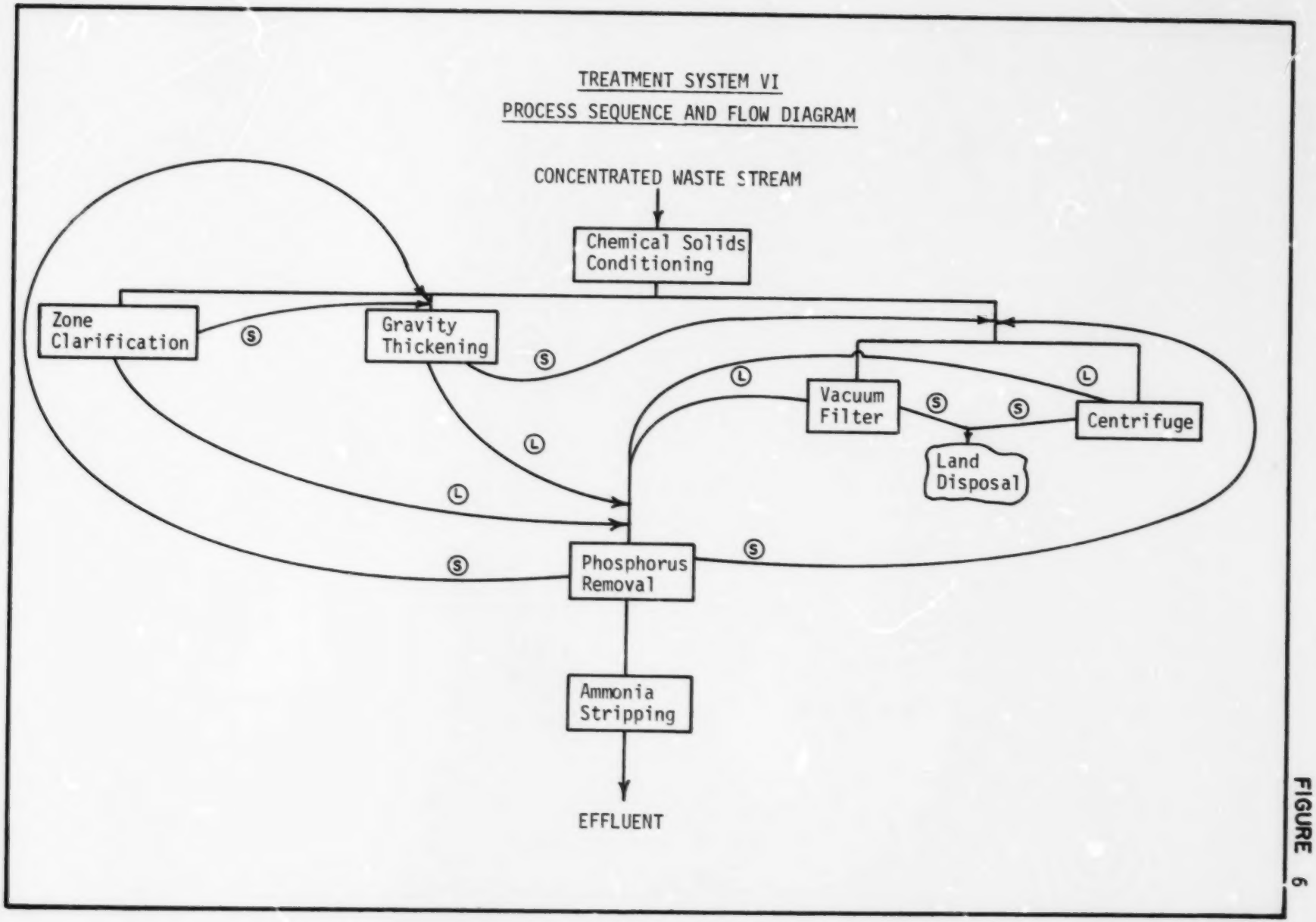

TREATMENT SYSTEM VI
PROCESS SEQUENCE AND FLOW DIAGRAM
CONCENTRATED WASTE STREAM
Chemical Solids Conditioning
Zone Clarification
Gravity Thickening
Vacuum Filter
Centrifuge
Land Disposal
Phosphorus Removal
Ammonia Stripping
EFFLUENT
S
L

FIGURE 6

TREATMENT SYSTEMS VII AND VIII
PROCESS SEQUENCE AND FLOW DIAGRAM

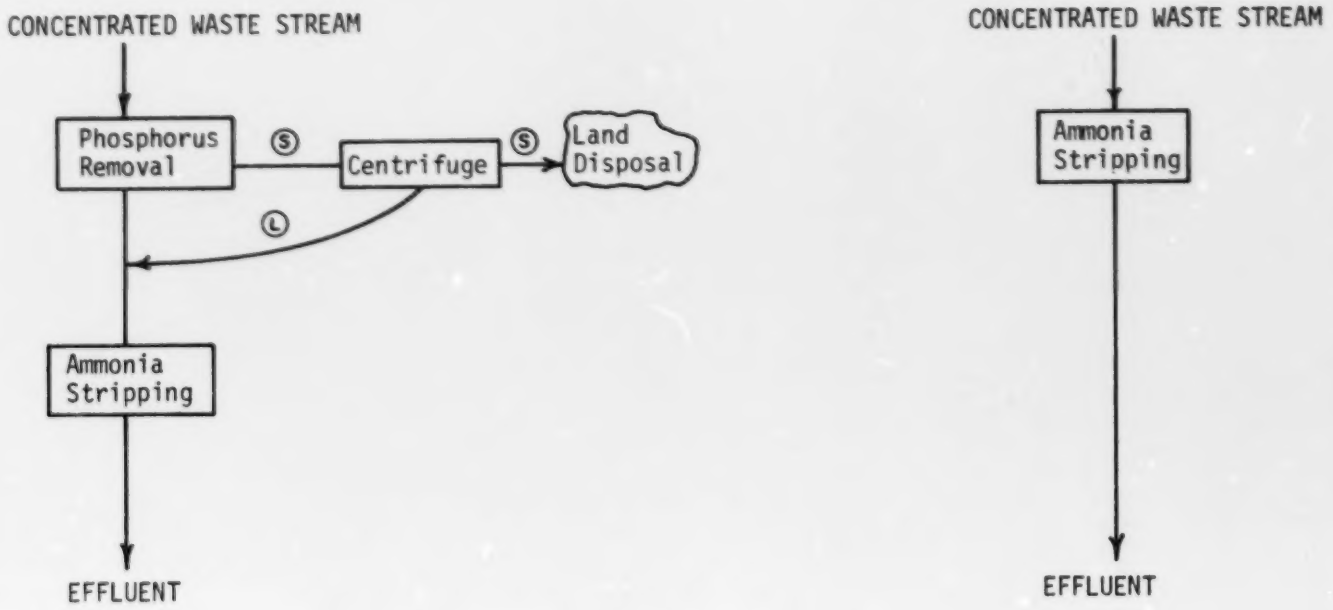


FIGURE 7